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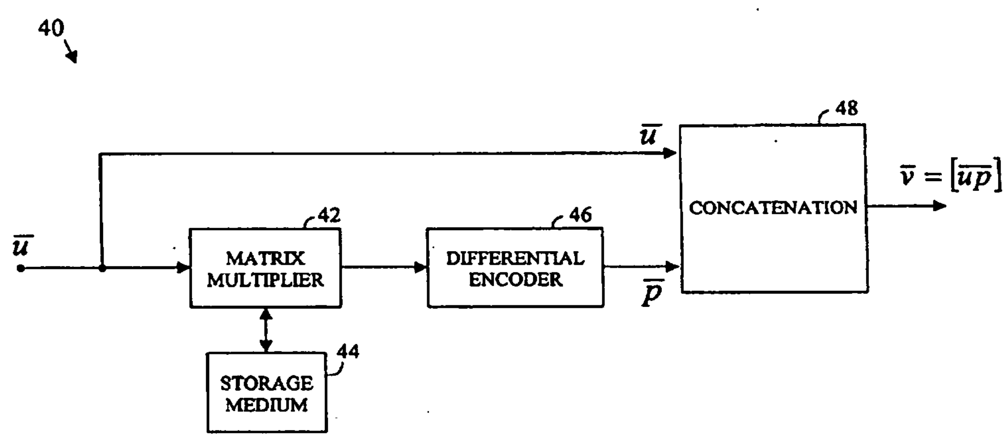
(54) **Title:** METHOD AND APPARATUS FOR IMPLEMENTING A LOW DENSITY PARITY CHECK CODE IN A WIRELESS SYSTEM



(57) **Abstract:** A low density parity check (LDPC) code is used within a wireless apparatus to perform forward error correction (FEC) coding. Encoding comprises the multiplication (42) with a transpose of a porti9on (44) of a parity check matrix followed by differential encoding (46). In at least embodiment of the invention, a (2000, 1600) bit-length LDPC code is used.

WO 2005/069527 A1

METHOD AND APPARATUS FOR IMPLEMENTING A LOW DENSITY PARITY CHECK CODE IN A WIRELESS SYSTEM

The present application claims the benefit of U.S. Provisional Application Serial No. 60/536071, filed Jan 12, 2004, entitled "A SYSTEM APPARATUS AND ASSOCIATED METHODS FOR HIGH THROUGHPUT WIRELESS NETWORKING."

TECHNICAL FIELD

The invention relates generally to wireless communications and, more particularly, to error correction coding schemes for use in wireless systems.

BACKGROUND

Wireless channels are often plagued by noise and/or interference effects that can compromise the quality of the communication flowing there through. One strategy for addressing these concerns involves the use of a forward error correction code to encode data before it is transmitted. The forward error correction code adds redundant information to the original data that allows errors in transmission to be corrected after signal reception. Structures and techniques are needed for reliably and efficiently implementing forward error correction in wireless systems.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram illustrating an example wireless network arrangement in accordance with an embodiment of the present invention;

Fig. 2 is a block diagram illustrating an example orthogonal frequency division multiplexing (OFDM) transmitter chain that may be used within a wireless device in accordance with an embodiment of the present invention;

Fig. 3 is a block diagram illustrating an example LDPC encoder in accordance with an embodiment of the present invention;

Fig. 4 is a diagram illustrating a Tanner graph that describes an example LDPC code; and

Fig. 5 is a flowchart illustrating an example method for use in processing data within a wireless device in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings that show, by way of illustration, specific embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. It is to be understood that the various embodiments of the invention, although different, are not necessarily mutually exclusive. For example, a particular feature, structure, or characteristic described herein in connection with one embodiment may be implemented within other embodiments without departing from the spirit and scope of the invention. In addition, it is to be understood that the location or arrangement of individual elements within each disclosed embodiment may be modified without departing from the spirit and scope of the invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims, appropriately interpreted, along with the full range of equivalents to which the claims are entitled. In the drawings, like numerals refer to the same or similar functionality throughout the several views.

Fig. 1 is a block diagram illustrating an example wireless network arrangement 10 in accordance with an embodiment of the present invention. As illustrated, one or more wireless user devices 12, 14, 16 are communicating with a wireless access point (AP) 18 via corresponding wireless links. The AP 18 provides access to a network for the user devices 12, 14, 16 (e.g., a private network, a public network, the Internet, a public switched telephone network, a local area network (LAN), a municipal area network (MAN), a wide area network

(WAN), and/or others). The wireless user devices 12, 14, 16 may include any form of device that may be used to wirelessly access a network including, for example, a laptop, desktop, palmtop, or tablet computer having wireless networking capability, a personal digital assistant (PDA) having wireless networking capability, a cellular telephone or other handheld wireless communicator, a pager, and/or others. The wireless links between the wireless devices 12, 14, 16 and the access point 18 may experience noise and/or various interference effects that can compromise communication quality. To overcome such problems, forward error correction may be used. That is, a forward error correction (FEC) coder may be provided within a transmitting device to encode data before it is wirelessly transmitted. When the signal is received, a FEC decoder may be used to decode the signal. The FEC decoder is capable of detecting and correcting one or more errors in the received data. In this manner, errors caused by noise and/or interference effects in the channel may be overcome. In one aspect of the present invention, a low density parity check (LDPC) code is used as a FEC code within a wireless device.

In at least one embodiment, features of the present invention are implemented within an orthogonal frequency division multiplexing (OFDM) based wireless system. Fig. 2 is a block diagram illustrating an example OFDM transmitter chain 20 that may be used within a wireless device (e.g., a wireless user device, a wireless access point, etc.) in accordance with an embodiment of the present invention. As illustrated, the transmitter chain 20 may include one or more of: a FEC coder 22, a mapper 24, a serial to parallel converter 26, an inverse fast Fourier transform (IFFT) unit 28, a guard interval (GI) addition unit 30, a wireless transmitter 32, and one or more transmit antennas 34. The FEC coder 22 receives user data at an input thereof and encodes the data using a forward error correction code. As will be described in greater detail, in at least one embodiment, the FEC coder 22 may utilize a special form of low density parity check (LDPC) code to perform the coding. The mapper 24 receives code words from the FEC coder 22 and maps the code words based upon a predetermined modulation constellation. Any form of modulation scheme may be used, including, for example, binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), 16 symbol quadrature amplitude modulation (16-QAM), 64 symbol quadrature amplitude modulation (64-QAM), and/or others. The serial to parallel converter 26 transforms a serial stream of modulation symbols output by the mapper 24 into a parallel format for delivery to the IFFT 28. The IFFT 28 performs an inverse fast Fourier transform on the modulation symbols input thereto to

convert the symbols from a frequency domain representation to a time domain representation. Although illustrated as an inverse fast Fourier transform in Fig. 2, it should be understood that any form of inverse discrete Fourier transform may be used in the transmitter chain 20.

The GI addition unit 30 adds a guard interval to the time domain signal representation output by the IFFT 28. Guard intervals are placed in transmitted signals to, among other things, increase the immunity of the signals to, for example, multipath effects in the channel. The wireless transmitter 32 is operative for performing functions such as, for example, up-converting the signal, power amplifying the signal, etc. before transmission. One or more transmit antennas 34 may be provided to facilitate signal transmission into the wireless channel. Any form of antenna(s) may be used including, for example, a dipole, a patch, a helix, an antenna array, and/or others. In at least one embodiment, antenna diversity techniques are implemented. In some other embodiments, multiple input, multiple output (MIMO) techniques are used. Other forms of wireless transducer may alternatively be used instead of antennas (e.g., a infrared (IR) diode in an IR-based wireless system, etc.).

It should be appreciated that the transmitter chain 20 of Fig. 2 is merely illustrative of one possible transmitter architecture that may utilize features of the invention. Many other architectures may alternatively be used. In at least one embodiment, a transmitter chain is used that is configured in accordance with an IEEE 802.11 wireless networking standard (ANSI/IEEE Std 802.11-1999 Edition and its progeny). Other wireless standards may alternatively or additionally be used.

As described above, in at least one embodiment of the invention, the FEC coder 22 may utilize a low density parity check (LDPC) code to perform the forward error correction coding. In a general analysis, an (n,k) LDPC code has k information bits and n coded bits with code rate r = k/n. A parity check matrix H of dimension (n-k)×n may be developed that fully describes the LDPC code. The parity check matrix H defines a set of equations:

$$\bar{v} \cdot H^t = 0 \qquad \text{(Equation 1)}$$

for all code words v of the code, where H^t is the transpose of parity check matrix H. An example parity check matrix H and the corresponding expanded parity check equations are shown below for an LDPC code (9,3):

$$H=\begin{bmatrix} 1 & & & 1 & & & 1 & & \\ & 1 & & & 1 & & & 1 & \\ & & 1 & & & 1 & & & 1 \\ 1 & & & & 1 & & & & 1 \\ & 1 & & & & 1 & 1 & & \\ & & 1 & 1 & & & & 1 & \end{bmatrix} \Longleftrightarrow \begin{cases} v_1+v_4+v_7=0 \\ v_2+v_5+v_8=0 \\ v_3+v_6+v_9=0 \\ v_1+v_5+v_9=0 \\ v_2+v_6+v_7=0 \\ v_3+v_4+v_8=0 \end{cases}.$$

where v_k represents the bits of the codeword v. LDPC codes may be encoded via a generator matrix G. For a given information vector $\bar{u}$ to be encoded, the corresponding code word $\bar{v}$ may be generated as follows:

$$\bar{v}=\bar{u}\cdot G \qquad \text{(Equation 2)}$$

From equations 1 and 2, it follows that:

$$\bar{u}\cdot G\cdot H^t=0 \qquad \text{(Equation 3)}$$

Since $\bar{u}$ is an arbitrary vector, the following relationship applies:

$$G\cdot H^t=0 \qquad \text{(Equation 4)}$$

For a given parity check matrix H, there will typically be 2^k different G matrices that satisfy Equation 4, provided the rank of the H matrix is n-k. One of these generator matrices has the format:

$$G=[I_{k\times k}\mid P_{k\times(n-k)}] \qquad \text{(Equation 5)}$$

where $I_{k\times k}$ is a k×k identity matrix and $P_{k\times(n-k)}$ is a k×n-k matrix. A coder implementing the generator matrix of Equation 5 is known as a systematic encoder since the first k bits of the code word are identical to the k information bits.

The parity check matrix H for an LDPC code may be represented as having two sub-matrices, as follows:

$$H=[H_1|H_2] \qquad \text{(Equation 6)}$$

where sub-matrix H_1 has dimension (n-k)*k and sub-matrix H_2 has dimension (n-k)*(n-k). According to Equation 4, and assuming that H_2 is non-singular, it follows that:

$$I \cdot H_1{}^{t} + P \cdot H_2{}^{t} = 0 \Rightarrow P = H_1{}^{t} H_2{}^{-t} \qquad \text{(Equation 7)}$$

and the codeword $\bar{v}$ is in the format:

$$\bar{v} = \bar{u} \cdot G = [\bar{u} \mid \bar{u}P] = [\bar{u} \mid \bar{u}H_1{}^{t} H_2{}^{-t}] \qquad \text{(Equation 8)}$$

For some LDPC codes, high encoding complexity may arise if a high density H_2^{-t} matrix is used in Equation 8 above. However, in at least one embodiment of the present invention, the sub-matrix H_2 is implemented as $f(D) = 1 + D$, which allows H_2^{-t} to be realized using a well known differential encoder. The encoding process in such an embodiment may be expressed as:

$$\bar{v} = [\bar{u} \mid \bar{u}H_1{}^{t} H_2{}^{-t}] = \left[\bar{u} \mid \bar{u}H_1{}^{t} \frac{1}{1+D}\right] \qquad \text{(Equation 9).}$$

where D is a unit delay.

Fig. 3 is a block diagram illustrating an example LDPC encoder 40 in accordance with an embodiment of the present invention. The LDPC encoder 40 may be implemented as part of, for example, the FEC unit 22 of Fig. 2 or FEC functionality within other wireless devices. As illustrated, the LDPC encoder 40 includes: a matrix multiplier 42, a storage medium 44, a differential encoder 46, and a concatenation unit 48. The storage medium 44 is operative for storing a representation of the sub-matrix H_1 (or the entire parity check matrix H) for use in LDPC encoding. The matrix representation stored on the storage medium 44 may be in conventional matrix form, in list file form (as in Appendix A), in transpose form, or in any other form that is descriptive of the content of the matrix.

Although not shown, the information stored within the storage medium 44 may also be used to perform LDPC decoding within the corresponding wireless apparatus (i.e., during receive operations). Any type of storage medium may be used including, for example, a semiconductor memory, a read only memory (ROM), a random access memory (RAM), an erasable programmable read only memory (EPROM), an electrically erasable programmable read only memory (EEPROM), a flash memory, a magnetic or optical card, a magnetic disk, an optical disk, a CD-ROM, a magneto-optical disk, and/or other forms of machine readable storage. The storage medium 44 may be a dedicated storage unit (e.g., to store only the parity check matrix H, the sub-matrix H_1^t, etc.) or it may also be used to store other information.

The matrix multiplier 42 receives an information vector $\bar{u}$ at an input thereof. The matrix multiplier 42 then performs a matrix multiplication of the vector $\bar{u}$ and the sub-matrix H_1^t. The result of the matrix multiplication is then delivered to the differential encoder 46 which performs a differential encoding operation thereon (i.e., $\frac{1}{1+D}$). The matrix multiplier 42 and the differential encoder 46 may operate independently of one another or their operation may be pipelined (e.g., once a bit is output from the matrix multiplier 42 it is immediately used by the differential encoder 46). The output of the differential encoder 46 is vector $\bar{p}$. The concatenation unit 48 concatenates the original information vector $\bar{u}$ with the vector $\bar{p}$ to generate the codeword $\bar{v}$. The codeword $\bar{v}$ may then be delivered to a next processing stage within a wireless transmitter chain (e.g., mapper 24 in the transmitter chain 20 of Fig. 2).

In at least one embodiment of the present invention, a (2000, 1600) LDPC code is implemented within the transmitter chain of a wireless apparatus. A list file describing a parity check matrix H that is used in one such implementation is set out in Appendix A herein. The list file of Appendix A describes the data within the corresponding parity check matrix. The parity check matrix H of Appendix A (or a portion thereof) may be stored within, for example, the storage medium 44 of Fig. 3. In at least one embodiment, only the portion of the parity check matrix H of Appendix A that corresponds to sub-matrix H_1 (or the transpose thereof) is stored within the storage medium 44 (i.e., the columns having a weight of 4 in the matrix description of Appendix A). The sub-matrix H_1 of the parity check matrix H of Appendix A is relatively low-

density with a uniform column weight of four. The LDPC code corresponding to the matrix H of Appendix A has been designed to provide good performance with variable-length data blocks, while still achieving a manageable implementation complexity. The codeword length has been selected to provide a good tradeoff between performance and complexity for use in wireless (and some wireline) applications. It should be appreciated that small variations may be made to the parity check matrix H of Appendix A with little or no degradation in performance. As used herein, a matrix is "substantially as described in the list file of Appendix A" if the matrix is the same as the matrix described in Appendix A or the matrix varies from the matrix described in Appendix A in a manner that produces little or no degradation in performance.

It should be understood that the parity check matrix H described in Appendix A is merely one example of a parity check matrix that may be used in accordance with embodiments of the present invention. In other embodiments, other parity check matrices may be used.

As described above, the parity check matrix H of Appendix A is described using a list file. This method of matrix description will be discussed below. A parity check matrix H will typically include ones and zeros in locations throughout the matrix. The list file of Appendix A describes the locations of these one and zeros for the subject matrix. A full definition of an LDPC code can be accomplished through identification of the locations of the "edges" between the "variable nodes" (codeword bits) and "check nodes" (parity relationships). Fig. 4 is a diagram illustrating a Tanner graph 50 that describes an example LDPC code. The Tanner graph 50 illustrates the arrangement of the check nodes 52, the variable nodes 54, and the "edges" 56 connecting them for the corresponding code. The codeword is made up of the bits represented by the variable nodes 54. For the code of Fig. 4, each codeword has ten bits. Each check node 52 represents a parity relationship between the codeword bits represented by the variable nodes 54 connected to it by the edges 56. The number of edges 56 connected to a check node 52 is called the "degree" of the check node 52. Likewise, the number of edges 56 connected to a variable node 54 is called the "degree" of the variable node 54. For the illustrated code, all check nodes 52 are of degree eighteen, all variable nodes 54 related to the systematic information bits are of degree four, and all variable nodes 54 corresponding to parity bits are of degree two, except for the last, which is of degree one.

Since the organization of the edges in LDPC codes appears random, the edge locations must be explicitly defined by means of a list. A straightforward means of describing a code by means of such a list follows. The matrix H = [H_1 H_2] comprises a regular matrix H_1 with constant column weight 4 and a weight-2 lower-triangular-inverse matrix H_2 for efficient encoding purposes. An LDPC code list file may contain three parts to fully describe a parity check matrix H (i.e., all of the ones of the matrix): (a) matrix size (column, row); (b) column weights (number of ones) of each column; and (c) locations of ones in each column. It should be noted that the convention for the indices is zero-based, with the index of the first element of each column being zero. An example H matrix for a (9,3) LDPC code follows:

$$H = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 \end{bmatrix}$$

and the corresponding list file is:

```
9 6
2 2 2 2 2 2 2 2 2
0 3
1 4
2 5
0 4
1 5
2 3
0 5
1 3
2 4
```

The list file set out in Appendix A for the (2000, 1600) LDPC code follows the same basic

approach.

Fig. 5 is a flowchart illustrating an example method 60 for use in processing data within a wireless device in accordance with an embodiment of the present invention. Input data is first matrix multiplied by a transpose of a first portion (i.e., H_1^t) of a parity check matrix H (block 62). The parity check matrix H (or some portion thereof) may be stored within a storage medium of the wireless device. In at least one embodiment, the parity check matrix H described in Appendix A is used. A result of the matrix multiplication may then be processed by a differential encoder to generate coded data (block 64). The original input data and the coded data are then concatenated to form a code word (block 66). A wireless signal is subsequently generated and transmitted that includes the code word (block 68). Other code words may also be part of the transmission. In at least one embodiment, the wireless signal is an orthogonal frequency division multiplexing (OFDM) signal. In at least one implementation, the method 60 of Fig. 5 (or a variant thereof) is embodied as a plurality of instructions stored on a machine readable storage medium that may be executed by a digital processing device.

The inventive techniques and structures may be used in any of a wide variety of different wireless devices, components, and systems. For example, in various embodiments, features of the invention may be implemented within laptop, desktop, palmtop, and/or tablet computers having wireless networking functionality, personal digital assistants (PDAs) having wireless networking functionality, cellular telephones and other handheld wireless communicators, pagers, satellite communication devices, devices for use in point to point wireless links, devices for use in local multipoint distribution systems (LMDS) and/or multi-channel multipoint distribution services (MMDS), wireless network interface cards (NICs) and other network interface structures, integrated circuits, and/or other devices.

In the foregoing detailed description, various features of the invention are grouped together in one or more individual embodiments for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed invention requires more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive aspects may lie in less than all features of each disclosed embodiment.

Although the present invention has been described in conjunction with certain embodiments, it is to be understood that modifications and variations may be resorted to

without departing from the spirit and scope of the invention as those skilled in the art readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and the appended claims.

APPENDIX A

The list file for an example (2000, 1600) LDPC code is set out below:

```
2000 400
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
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4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
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4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
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190 339 362 364
10 67 187 338
2 132 168 263
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59 157 188 224
139 220 320 349
69 202 336 385
20 92 313 331
44 79 316 392
104 177 254 335
4 199 234 308
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89 217 352 378
83 156 175 211
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141 161 342 353
336 375 381 397
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What is claimed is:

1. A wireless apparatus comprising:

a forward error correction (FEC) coder to encode digital data using a low density parity check (LDPC) code, said FEC coder including:

a matrix multiplication unit to multiply input data by a transpose of a first portion of a parity check matrix to generate modified data;

a differential encoder to differentially encode said modified data to generate coded data; and

a concatenation unit to concatenate the input data and the coded data to form a code word; and

a wireless transmitter to transmit a wireless signal that includes said code word.

2. The wireless apparatus of claim 1, wherein:

said wireless signal is an orthogonal frequency division multiplexing (OFDM) signal.

3. The wireless apparatus of claim 1, further comprising:

a mapper, between said FEC coder and said wirelews transmitter, to map said code word based on a predetermined modulation scheme; and

an inverse discrete Fourier transform unit to convert mapped data from a frequency domain representation to a time domain representation.

4. The wireless apparatus of claim 1, wherein:

said parity check matrix is substantially as described in the list file of Appendix A.

5. The wireless apparatus of claim 1, wherein:

said parity check matrix is the same as the matrix described in the list file of Appendix A.

6. The wireless apparatus of claim 1, further comprising:

a storage medium to store a representation of at least said first portion of said parity check matrix for use by said matrix multiplication unit.

7. The wireless apparatus of claim 6, wherein:

said storage medium is operative to store a representation of the entire parity check matrix.

8. The wireless apparatus of claim 6, wherein:

said storage medium is operative to store a matrix that is substantially as described in the list file of Appendix A.

9. The wireless apparatus of claim 6, wherein:

said storage medium is operative to store a matrix that is a portion of a matrix that is substantially as described in the list file of Appendix A, said portion of said matrix being a portion having columns of weight 4.

10. The wireless apparatus of claim 1, wherein:

said LDPC code is a (2000, 1600) bit-length code.

11. The wireless apparatus of claim 1, wherein:

said wireless apparatus is a wireless user device for use in a wireless network.

12. The wireless apparatus of claim 1, wherein:

said wireless apparatus is a wireless access point.

13. The wireless apparatus of claim 1, wherein:

said wireless apparatus is a wireless network interface module.

14. The wireless apparatus of claim 1, wherein:

said wireless apparatus is an integrated circuit.

15. A method comprising:

matrix multiplying input data by a transpose of a first portion of a parity check matrix;

processing a result of said matrix multiplication using differential encoding to generate coded data;

concatenating said input data and said coded data to form a code word; and generating and transmitting a wireless signal that includes said code word.

16. The method of claim 15, wherein:
said wireless signal is an orthogonal frequency division multiplexing (OFDM) signal.

17. The method of claim 15, further comprising:
accessing a storage medium storing a representation of at least a portion of said parity check matrix before matrix multiplying.

18. The method of claim 15, wherein:
said parity check matrix is substantially as described in the list file of Appendix A.

19. The method of claim 15, wherein:
said parity check matrix is the same as the matrix described in the list file of Appendix A.

20. The method of claim 15, wherein:
said parity check matrix defines a (2000, 1600) bit-length LDPC code.

21. The method of claim 15, wherein:
generating and transmitting a wireless signal includes mapping said code word into modulation symbols and processing said modulation symbols using an inverse discrete Fourier transform.

22. An article comprising a machine readable storage medium having a representation of at least a portion of a parity check matrix stored thereon, said parity check matrix being substantially as described in the list file of Appendix A.

23. The article of claim 22, wherein:
said machine readable storage medium has a representation of the entire parity check matrix stored thereon.

24. The article of claim 22, wherein:

said machine readable storage medium has a portion of said parity check matrix stored thereon that includes all columns of weight 4.

25. The article of claim 22, wherein:

said parity check matrix is the same as the matrix described in the list file of Appendix A.

26. The article of claim 22, wherein:

said parity check matrix defines a (2000, 1600) bit-length LDPC code.

27. The article of claim 22, wherein:

said article includes a wireless communication device.

28. The article of claim 22, wherein:

said article comprises only said machine readable storage medium.

29. The article of claim 22, wherein:

said machine readable storage medium comprises at least one of the following: a semiconductor memory, a read only memory (ROM), a random access memory (RAM), an erasable programmable read only memory (EPROM), an electrically erasable programmable read only memory (EEPROM), a flash memory, a magnetic card, an optical card, a magnetic disk, an optical disk, a CD-ROM, and a magneto-optical disk.

30. A system comprising:

a forward error correction (FEC) coder to encode digital data using a low density parity check (LDPC) code, said FEC coder including:

a matrix multiplication unit to multiply input data by a transpose of a first portion of a parity check matrix to generate modified data;

a differential encoder to differentially encode said modified data to generate coded data; and

a concatenation unit to concatenate the input data and the coded data to form a code word;

a wireless transmitter to transmit a wireless signal that includes said code word; and

at least one dipole antenna coupled to said wireless transmitter to facilitate transmission of said wireless signal.

31. The system of claim 30, wherein:

said wireless signal is an orthogonal frequency division multiplexing (OFDM) signal.

32. The system of claim 30, further comprising:

a storage medium to store a representation of at least said first portion of said parity check matrix for use by said matrix multiplication unit.

33. The system of claim 30, wherein:

said parity check matrix is substantially as described in the list file of Appendix A.

34. An article comprising a storage medium having instructions stored thereon that, when executed by a computing platform, operate to:

matrix multiply input data by a transpose of a first portion of a parity check matrix;

process a result of said matrix multiplication using differential encoding to generate coded data;

concatenate said input data and said coded data to form a code word; and

generate and transmit a wireless signal that includes said code word.

35. The article of claim 34, wherein:

said wireless signal is an orthogonal frequency division multiplexing (OFDM) signal.

36. The article of claim 34, wherein said instructions, when executed by the computing platform, further operate to:

access a storage medium having at least a portion of said parity check matrix stored thereon before matrix multiplying.

37. The article of claim 34, wherein:
said parity check matrix is substantially as described in the list file of Appendix A.

38. The article of claim 34, wherein:
said parity check matrix defines a (2000, 1600) bit-length LDPC code.

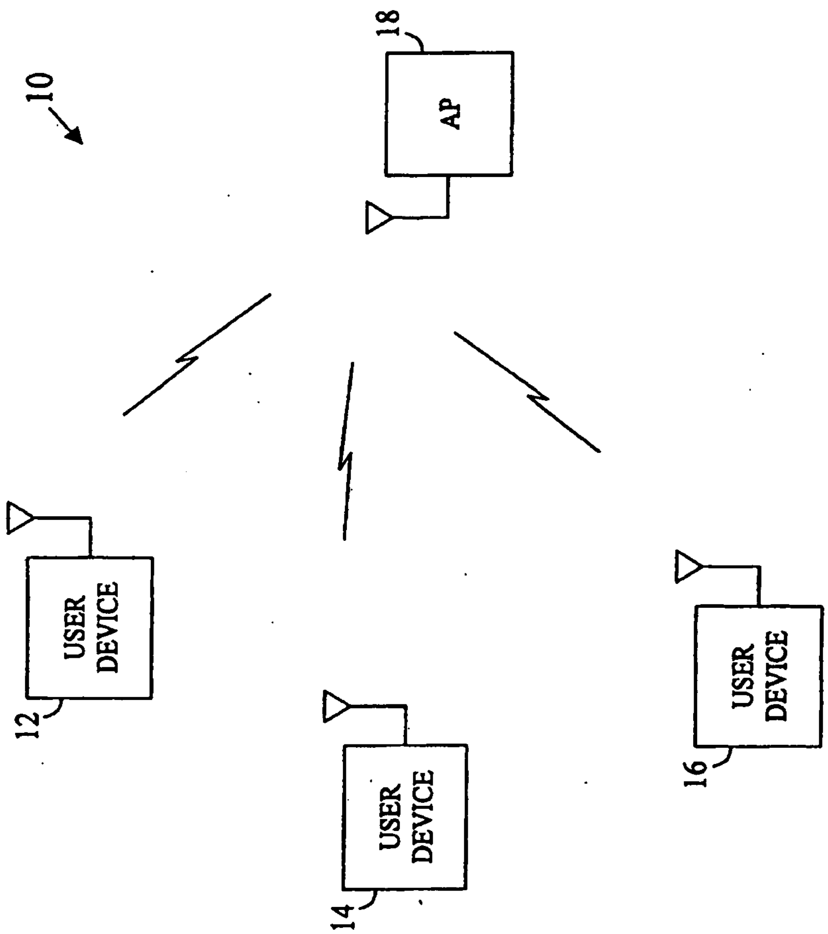
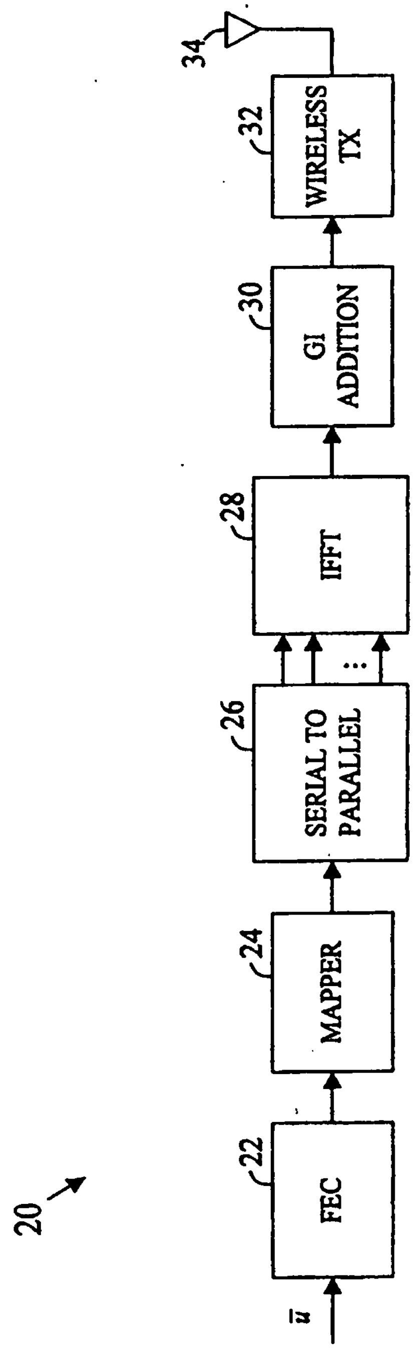


Fig. 1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FEC
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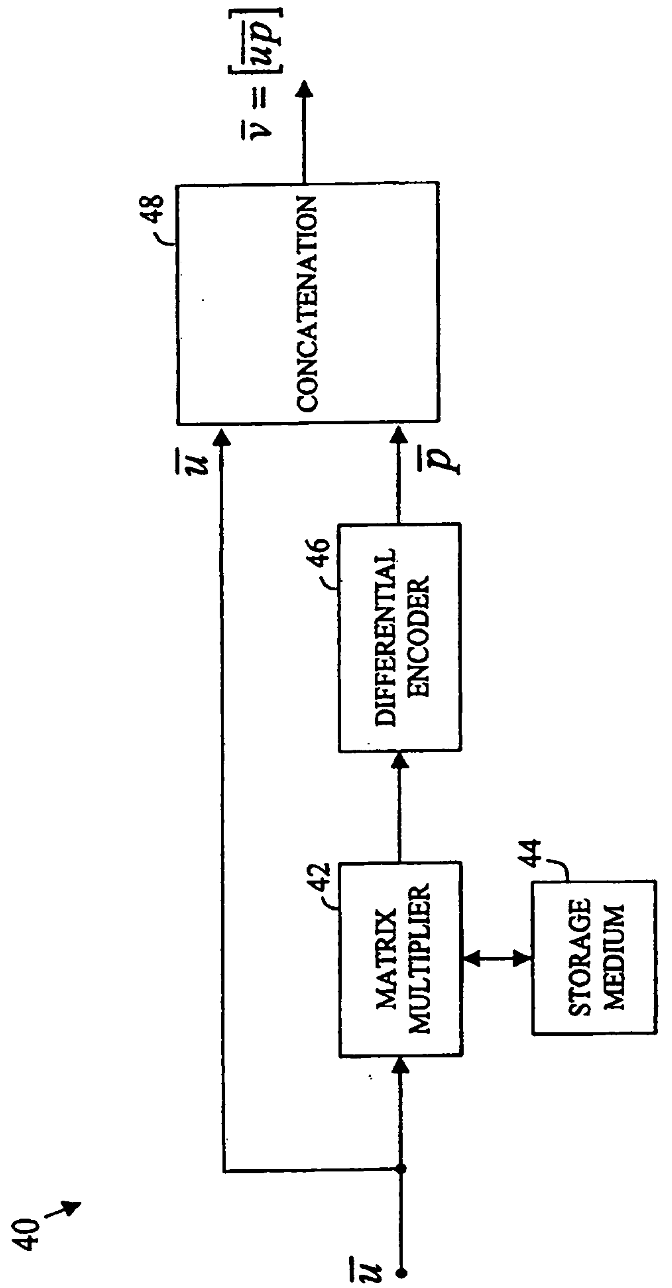
Fig. 2



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48
CONCATENATION
$\bar{u}$
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DIFFERENTIAL ENCODER
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MATRIX MULTIPLIER
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STORAGE MEDIUM
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Fig. 3

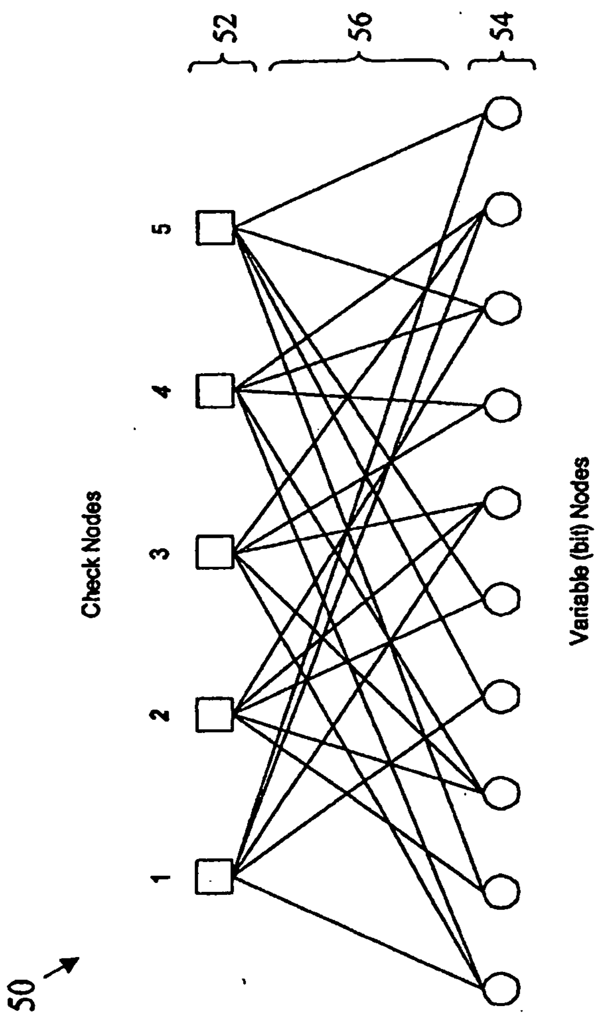
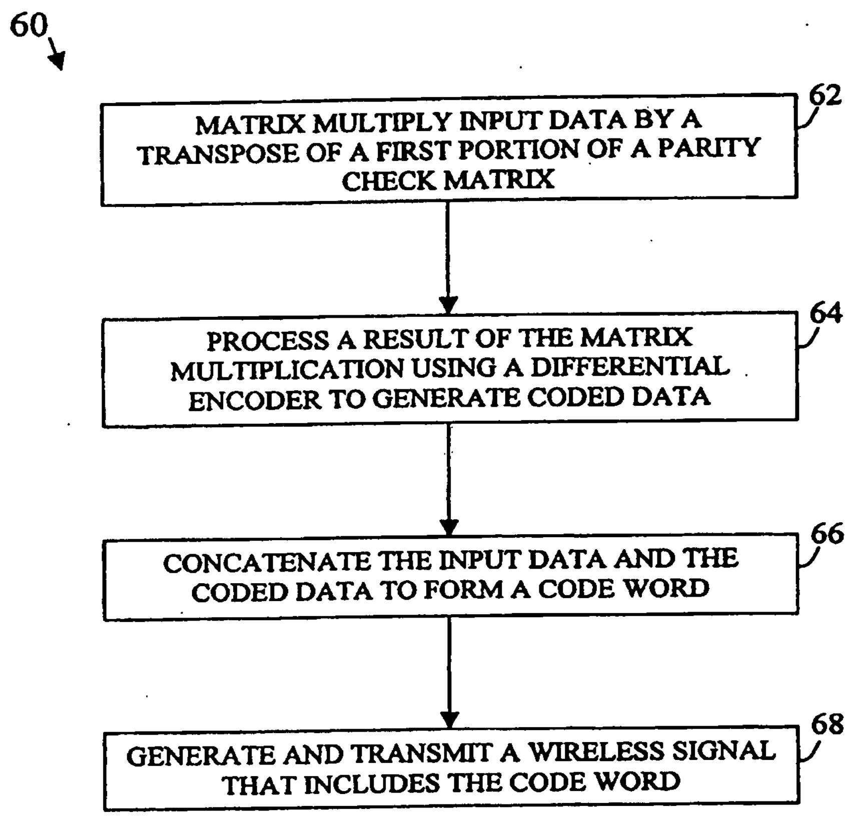


Fig. 4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MATRIX MULTIPLY INPUT DATA BY A TRANSPOSE OF A FIRST PORTION OF A PARITY CHECK MATRIX
62
PROCESS A RESULT OF THE MATRIX MULTIPLICATION USING A DIFFERENTIAL ENCODER TO GENERATE CODED DATA
64
CONCATENATE THE INPUT DATA AND THE CODED DATA TO FORM A CODE WORD
66
GENERATE AND TRANSMIT A WIRELESS SIGNAL THAT INCLUDES THE CODE WORD
68

Fig. 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2005/000948

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04L1/00 H03M13/11

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04L H03M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	YANG M ET AL: "DESIGN OF EFFICIENTLY ENCODABLE MODERATE-LENGTH HIGH-RATE IRREGULAR LDPC CODES" PROCEEDINGS OF THE ANNUAL CONFERENCE ON COMMUNICATION, CONTROL AND COMPUTING, 2 October 2002 (2002-10-02), pages 1415-1424, XP009042018 page 1419 - page 1422; figure 1a -----	1-21, 30-38

-/--

[X] Further documents are listed in the continuation of box C.

[ ] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 May 2005	01/06/2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Marzenke, M

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	FUTAKI H ET AL: "Performance of low-density parity-check (LDPC) coded OFDM systems" ICC 2002. 2002 IEEE INTERNATIONAL CONFERENCE ON COMMUNICATIONS. CONFERENCE PROCEEDINGS. NEW YORK, NY, APRIL 28 - MAY 2, 2002, IEEE INTERNATIONAL CONFERENCE ON COMMUNICATIONS, NEW YORK, NY : IEEE, US, vol. VOL. 1 OF 5, 28 April 2002 (2002-04-28), pages 1696-1700, XP010589776 ISBN: 0-7803-7400-2 page 1696 - page 1698; figure 3 -----	1-21, 30-38
A	SYED M J ET AL: "LDPC-based space-time coded OFDM systems performances over correlated fading channels" COMMUNICATIONS, 2003. APCC 2003. THE 9TH ASIA-PACIFIC CONFERENCE ON 21-24 SEPT. 2003, PISCATAWAY, NJ, USA,IEEE, vol. 2, 21 September 2003 (2003-09-21), pages 590-594, XP010688253 ISBN: 0-7803-8114-9 page 590; figure 1 -----	1-21, 30-38

International application No.
PCT/US2005/000948

INTERNATIONAL SEARCH REPORT

Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 22-29
because they relate to subject matter not required to be searched by this Authority, namely:
see FURTHER INFORMATION sheet PCT/ISA/210

2. [ ] Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.1

Claims Nos.: 22-29

Independent Claim 22 relates to an "article" comprising a machine readable storage medium that is merely characterised by the content of the information stored thereon - that is at least a portion of a parity check matrix being substantially as described in Appendix A of present application. Such subject-matter is however excluded from International search according to Rule 39.1(v) PCT (see PCT-Guidelines 9.02 and 9.11).

Any type of machine readable storage medium can be construed from Claim 22, for instance a conventional CD-ROM, a conventional MP3 player or a conventional personal computer (see also Claim 29 listing further possible interpretations). Claim 22 fails to define any structural or functional relationship whatsoever between the stored information and the storage medium. No technical effect can be derived from the fact that the CD-ROM, MP3 player or PC stores information, be it part of a parity check matrix, digitized music or a computer program code.

Consequently, Claim 22 has no technical character as it is solely defined by the content of the stored information (PCT-Guidelines 9.11).

The same applies to the subject-matter of dependent Claims 23-29. Claims 23-26 further specify the information stored in the storage medium and Claim 29 further specifies the type of storage medium used. Again, no technical interaction becomes apparent between the storage medium and the information stored thereon. This problem exists irrespective of whether the claimed "article" comprises only the storage medium (Claim 28) or also a wireless communication device (Claim 27) which does not interact in any way with the storage medium or the information stored.